Strong Line Metallicity Calibrators Applied to SDSS Galaxies

Sara L. Ellison
University of Victoria, Dept. of Physics & Astronomy, British Columbia, Canada

Lisa J. Kewley
Institute for Astronomy, University of Hawaii, Hawaii, USA

Abstract. We calculate the oxygen abundances for $\sim 45{,}000$ star-forming galaxies selected from the SDSS using nine popular 'strong-line' metallicity diagnostics. We find that individual galaxies can have metallicities which differ by factors of up to ~ 4, depending on the choice of abundance diagnostic. The resulting mass-metallicity relations subsequently exhibit significant offsets, with a range of 0.5 dex in metallicity at a given mass. This demonstrates that different metallicity diagnostics should not be used interchangeably for determining oxygen abundances. We also show that SDSS spectra are dominated by the central galactic component which introduces a noticeable aperture effect.

1 Introduction

The metallicity of a galaxy is a powerful diagnostic which represents the aggregate history of its star formation, mergers, gas infall and galactic winds. In other words, a single parameter encapsulates a complex record of a galaxy's past. For the most part, metallicities in nearby galaxies are measured through their HII region gas phase oxygen abundances. High S/N spectra of individual HII regions permit an explicit solution for the electron temperature, density and, ultimately, metallicity. Determination of metallicities 'directly' in this way, typically requires detection of [OIII] $\lambda\lambda 4959, 5007$, H$\beta$ and [OIII] $\lambda 4363$ (or some other auroral line). As the metallicity of the HII region increases, far-IR lines become the dominant coolant, so the optical auroral lines become increasingly weak. Very deep observations are therefore required to determine metallicities in regions of even moderate metallicities in local galaxies (e.g. Bresolin et al. 2004). Already at modest distances, the direct method of metallicity determination from electron temperatures therefore becomes impractical due to the difficulty of detecting any of the weak auroral lines. To circumvent this problem, a number of metallicity diagnostics have been developed which make use of only the stronger emission lines that can be readily observed out to even high redshifts (see the contribution by M. Pettini in these proceedings). These so-called 'strong-line' metallicity diagnostics have been calibrated in a variety of ways, utilise different sets of emission lines and are convenient for different redshift ranges. In this proceedings contribution, I describe work in which we have applied a range of metallicity diagnostics to a large, uniform sample of galaxies drawn from the SDSS and compare the metallicities derived in each case. We find that the oxygen abundance derived for a given galaxy can vary by up to a factor of ~ 4 depending on the choice of diagnostic.

2 Galaxy Sample Selection

Our dataset was selected from the 261054-galaxy SDSS sample described in Brinchmann et al. (2004) according to the following criteria:

1. Signal-to-noise (S/N) ratio of at least 3 in the strong emission-lines Hβ, [OIII] $\lambda 5007$, Hα, [NII] $\lambda 6584$, and [SII] $\lambda\lambda 6717, 31$. This S/N criterion is required for accurate classification of the galaxies into star-formation or AGN-dominated classes e.g. Kewley et al (2001) and Veilleux & Osterbrock (1987).
2. Fibre covering fraction $> 20\%$ of the total photometric g'-band light. Kewley, Jansen & Geller (2005) found that a flux covering fraction above this cut-off is required for metallicities to begin to approximate global values. Lower covering fractions can produce significant discrepancies between fixed-sized aperture and global metallicity estimates (although a 20 % covering fraction does not guarantee the absence of aperture effects, as we discuss in section 4).
3. Stellar mass estimates must be available from the catalog of Tremonti et al. (2004)

The resulting sample contains 45086 galaxies, spanning a large range in stellar mass ($10^8 - 10^{11.6}$ M$_\odot$) and metallicities $8.0 < \log(\mathrm{O/H}) + 12 < 9.4$, as calculated by Tremonti et al. (2004).

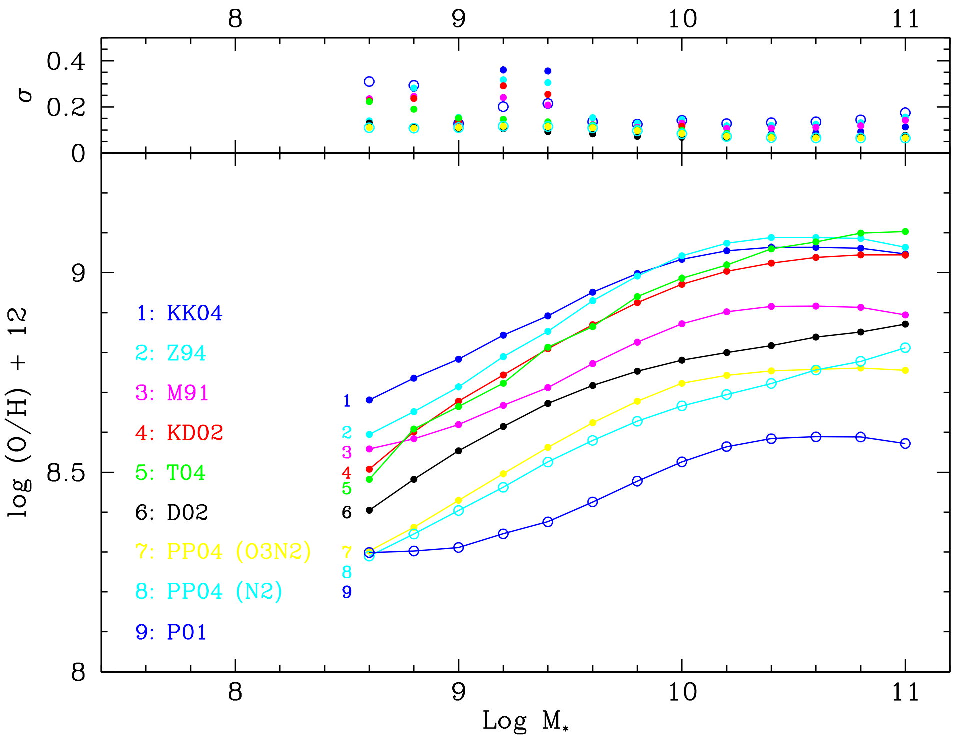


Figure 1: MZ relation for nine strong-line diagnostics binned by mass in units of log $M_\odot$). The top panel shows the RMS scatter for each calibration in each mass bin.

3 Metallicity Diagnostics

Strong-line metallicity diagnostics can be broadly separated into three categories: theoretical, empirical and combination. The first category utilises theoretical models to calibrate emission line flux ratios and includes the diagnostics of McGaugh (1991; M91), Kewley & Dopita (2002; KD02), Kobulnicky & Kewley (2004; KK04), Zaritsky, Kennicutt & Huchra (1994; Z94) and Tremonti et al. (2004; T04). Empirical methods rely on fitting a function to metallicities determined via direct methods versus strong line flux ratios, such as Pilyugin (2001; P01). Finally, the combination methods again determine a functional fit to data, but use a mix of direct metallicity determinations, supplemented with values (often at the high metallicity end) obtained via theoretical calibrations. Examples of combination calibrations include Denicolo et al. (2002; D02) and the two calibrations of Pettini & Pagel (2004; PP04). Each of these calibrations has associated advantages and disadvantages, many of which are discussed in detail by Kewley & Ellison (2005). For example, one of the disadvantages of a number of diagnostics which use the so-called R_{23} ratio of [OII] $\lambda3727$, [OIII] $\lambda4959, 5007$ and Hβ is that there are two metallicity solutions for any given flux ratio. Moreover, the range in rest wavelengths of these emission lines means that correction for internal galactic extinction becomes very important for accurate flux ratios. Although diagnostics which use the ratio of [NII]/Hα (e.g. D02, PP04) do not suffer from these problems, they are sensitive to the ionization parameter (the ratio of H ionizing photons to H atoms), and effectively 'saturate' at high metallicities.

We have applied the nine calibrations mentioned above to the sample of star-forming galaxies described in §2. To investigate the importance of diagnostic choice, we focus on the impact manifested in the mass-metallicity (MZ) relation recently studied by T04. In Figure 1 we show the MZ relation for the nine strong-line diagnostics. For clarity, we have binned the metallicities by mass and shown the median values of each bin. We see that the MZ relations exhibit the same general trends for all diagnostics: a rise in metallicity with mass up to a stellar mass log $M_\star \sim 10$ $M_\odot$ followed by a flattening at higher masses. However, there is considerable difference in the normalization of the MZ relation, with a range of 0.5 dex (a factor of 3) in metallicity for a given mass between diagnostics. Furthermore, in Figure 2 we show explicitly the comparison between two diagnostics, KK04 and P01, which shows that a given galaxy can have metallicities different by up to a factor of ~ 4 depending on diagnostic choice. This is a clear demonstration that although different metallicity diagnostics may be convenient for galaxies at different redshifts, consistency in metallicity determination is imperative when combining samples. If different strong-line calibrations are used, this will, at best, introduce a scatter in the MZ relation. At worst, a systematic offset could be introduced, leading to erroneous comparisons between the samples.

However, for some of the strong-line diagnostics, it may be possible to correct for systematic calibration differences. In a forth-coming paper (Kewley & Ellison 2005) we discuss the prospects for such corrections and

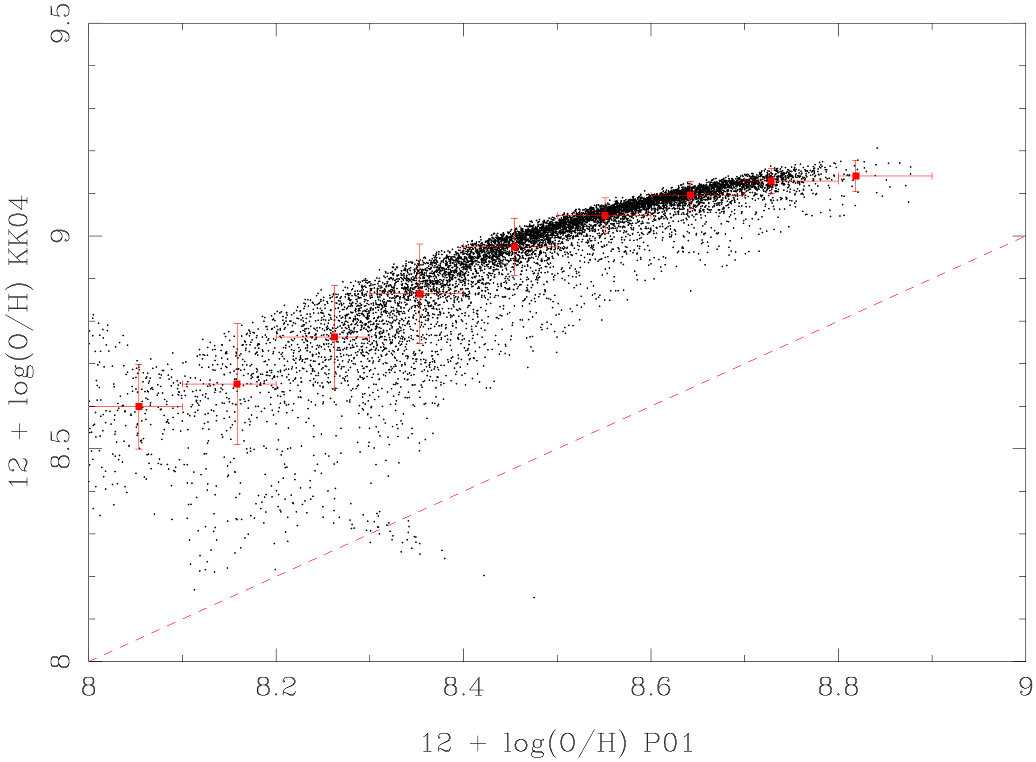


Figure 2: Oxygen abundances determined for SDSS galaxies using two different strong-line diagnostics; Pilyugin (2001) and Kobulnicky & Kewley (2004). The red points with error bars are binned medians and the dashed line shows a one-to-one relationship.

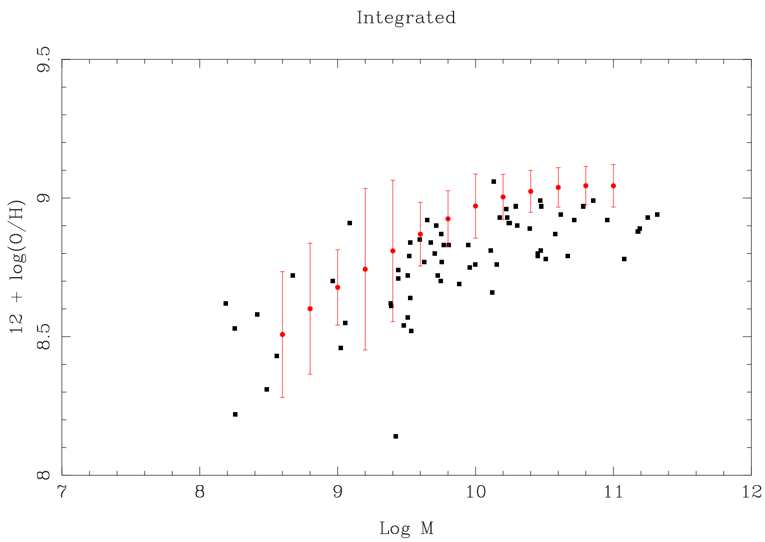
provide prescriptions for converting between the diagnostics discussed in this proceedings contribution.

4 Aperture Effects

We finish by briefly considering the effect of integrated fibre spectroscopy on the derived 'global' metallicity of a galaxy. The SDSS fibres are 3 arcsec in diameter, corresponding to a proper length of 5.5 kpc at $z = 0.1$ (H_0 = 70 km/s/Mpc, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$), the median redshift of our galaxy sample. What is the effect of only including the central component of the galaxy's light in our spectroscopic determination of metallicity? Using the Nearby Field Galaxy Survey (NFGS) of Jansen et al. (2000), Kewley et al. (2005) have suggested that if the covering fraction is less than 20%, aperture effects can cause errors up to 40% in the metallicities (and effects may persist in high luminosity galaxies even for significantly larger covering fractions). We investigate the impact of aperture effects in SDSS data by returning to the NFGS sample and determining its MZ relation. We calculate NFGS galaxy masses by combining 2MASS J band magnitudes with optical band passes, a technique which is comparable to determining the mass via spectral fitting (Drory, Bender & Hopp 2004). In both panels of Figure 3 we show again the MZ relation for the SDSS galaxies using the KD02 metallicity calibration. In the upper panel, we compare the SDSS data with KD02 metallicities for the *integrated* metallicities derived for the NFGS, calculated by combining slit spectra taken at many positions across the face of the galaxy. We see that although the lower mass NFGS galaxies trace well the SDSS MZ relation, the nearby galaxies appear to have a plateau at a lower metallicity (by ~ 0.15 dex). In the lower panel of Figure 3, we show the comparison of SDSS data with the *nuclear* NFGS metallicities, derived from a single long slit spectrum taken across the centre of the galaxy. Now we see a much better agreement with the SDSS. These results highlight how nuclear spectra yield higher metallicities than integrated spectra, as expected if strong abundance gradients are present. Again, this is cause for caution when comparing the SDSS galaxies with high redshift samples whose spectra will capture more of the peripheral light than the SDSS spectra which are weighted towards higher nuclear metallicities.

5 Conclusions

This work has provided us with two important caveats to keep in mind when dealing with galaxy metallicities. First, we have shown that considerable caution is required when dealing with metallicities derived from HII region strong line diagnostics. Although it is impossible to advise on which diagnostic yields the 'right' answer, we have



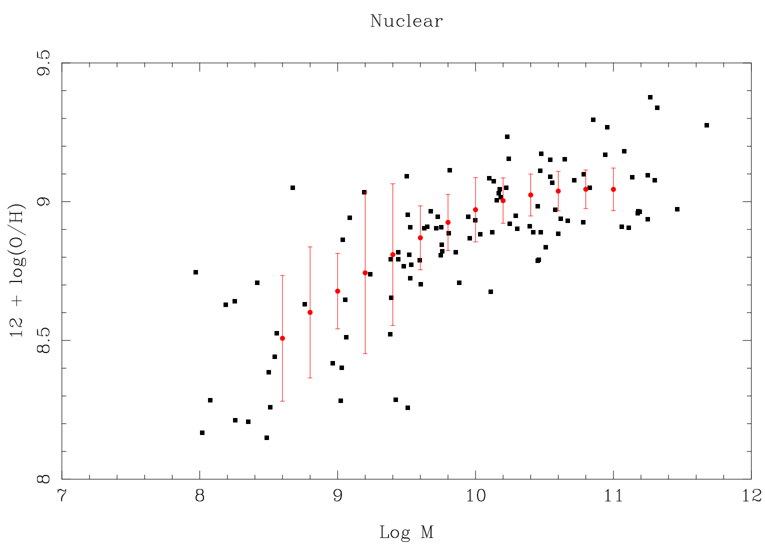


Figure 3: The SDSS MZ relation determined from the KD02 diagnostic, binned by mass (red points with RMS error bars, both panels) compared with the NFGS. In the top panel, the SDSS data are compared with integrated NFGS spectra (black points without error bars) which encompass the bulk of the galaxies' light. In the lower panel, nuclear NFGS metallicities were derived from slit spectra of just the central part of the galaxy.

shown that one must be consistent with the choice of metallicity calibration. Second, we have demonstrated that SDSS spectra are subject to considerable aperture effects. Since a fixed sized aperture (slit or fibre) will encompass different fractions of galaxy light as a function of redshift, it is important to account for aperture effects before comparing SDSS data with high redshift studies.

References

[1] Bresolin, F., Garnett, D., Kennicutt, R., 2004, ApJ, 615, 228

[2] Brinchmann, J., et al., 2004, astro-ph/0406220

[3] Denicolo, G., Terlevich, R., Terlevich, E., 2002, MNRAS, 330, 69

[4] Drory, N., Bender, R., Hopp, U., ApJ, 616, L103

[5] Jansen, R., Franx, M., Fabricant, D., Caldwell, N., 2000, ApJS, 126, 271

[6] Kewley, L. J., et al. 2001, ApJ, 556, 121

[7] Kewley, L. J., & Ellison, S. L., in preparation

[8] Kewley, L. J., & Dopita, M., 2002, ApJS, 142, 35

[9] Kewley, L. J., Jansen, R., Geller, M., 2005, PASP, 117, 227

[10] Kobulnicky, H., & Kewley, L. J., 2004, ApJ, 617, 240

[11] McGaugh, S., 1991, ApJ, 380, 140

[12] Pilyugin, L. S., 2001, A&A, 369, 594

[13] Pettini, M., & Pagel, B., 2004, MNRAS, 348, L59

[14] Tremonti, C., et al., 2004, ApJ, 693, 898

[15] Veilleux, S., & Osterbrock, D., 1987, ApJS, 63, 295

[16] Zaritsky, D., Kennicutt, R., Huchra, J., 1994, ApJ, 420, 87